

Thermal Design Guidelines

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ABSTRACT: This guideline contains thermal limit data for components, items, and materials used in the construction of Digital products. It provides the basis for each guideline limit and the specific location for measurement and verification purposes.

APPLICABILITY: This document applies to Digital personnel involved in the use or the setting of thermal limits.

STATUS: APPROVED 20-Sep-1990; use VTX SMC for current status.

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1 INTRODUCTION

As the discipline of thermal management of products has developed at Digital over the years, specific thermal limits for many components have been accepted as good design practice. However, in many cases, clear and coherent technical bases have not been established for thermal limits; currently, the limits used are those that have generally stood the test of time.

With the rapid growth and development of new processes, new materials, new technology, the move from computer room to office and factory, and increased competitiveness, these thermal limits must be defined, critically evaluated, and documented to ensure that Digital meets customer expectations, while remaining competitive and timely.

2 PURPOSE

To address these concerns, the goals of this guideline are as follows.

- a. To serve as a repository for historical and new thermal limit data for use in thermal design throughout Digital.
- b. To document the basis for each guideline limit and the specific location for measurement and verification purposes.
- c. To create a method for establishing or changing guidelines, and a means of communicating the revisions to the the thermal design community.

3 SCOPE

This guideline contains thermal limit data for components, items, and materials used in the construction of Digital products. Thermal limit data is recognized from a variety of sources, including:

- a. Reliability Assessment
(component failure over time, whether by gradual deterioration or thermal cycling)
- b. Safety Considerations
- c. Operability Assessment
(reversible, temperature related, electrical incompatibility)

Alternative methods are also presented for the generation of thermal limits by means other than the use of guideline values.

A comprehensive set of reference documents is listed in Appendix A to provide the user with the source data forming the technical basis for the limits.

4 THERMAL LIMITS

4.1 TYPES

Thermal Limits can be separated into two categories: maximum and design. Maximum limits are the values up to which continuous operation is considered to be safe or is warranted by the manufacturer of the item in question. Design limits are the values that are used as the basis for the general development of the thermal control approach and the setting of specific thermal design parameters, or features, in the the design of a product.

4.2 DEFINITIONS

Thermal limit guidelines presently considered include:

- Design temperature
- Maximum temperature
- Design temperature range
- Design temperature rate of change

These are defined as follows.

Design Temperature Limit

The highest temperature at which a component, subassembly, or unit can reach, during steady-state conditions, in a powered product under design. It is the most important thermal design criterion as the meeting of this limit is the basis for the setting of all the thermal design parameters.

Maximum Temperature Limit

The highest temperature at which a component, subassembly, or unit is considered to be safe or is warranted for continuous operation at by the manufacturer.

Design Temperature Range Limit

The temperature range over which a component, subassembly, or unit can reach in a powered product under design.

Design Rate of Change of Temperature Limit

The temperature change per unit of time at which a component, subassembly, or unit can reach in a powered product under design.

4.3 NEED

As indicated in DEC STD 120, Section 4.2, design and maximum temperature limits are required. Design and maximum temperature range and rate of change of temperature limits are only required when relevant.

Design limits are usually lower than the corresponding maximum limits, thereby allowing some margin for changes, error or uncertainty as the design develops.

4.4 RESPONSIBILITY

As indicated in DEC STD 120, Section 2.2.1, the responsible engineer must ensure that thermal limits are defined for the product under design and that the product is designed to meet these limits.

To aid the responsible engineer in defining these limits, guideline data are presented in Sections 5 through 8. These values may be adopted, where appropriate, as outlined in DEC STD 120, Section 6.

4.5 IMPACT ON PRODUCT DESIGN

There are a number of questions that come up as thermal limits are set for a product under design. Included in these are the following.

- If thermal limits are met, will the product be thermally functional?
- Is it better to have lower or more stringent thermal limits?
- How accurate are the guideline thermal limits?
- Why not use maximum limits only?

The following are responses to these questions:

- These guideline limits have been in use at Digital for many years and have generally resulted in acceptable designs. However, simply meeting these limits is no guarantee that a product will be thermally acceptable.
- Product development will be best served by having thermal limits set that are relevant for the product and its application. While it is generally true that operation at lower temperature will be safer and more reliable, such a design effort may adversely affect cost and schedule and generally be inconsistent with overall product development requirements.

For example, the lowering of an IC design junction temperature limit from 110 C to 80 C could require a larger heatsink, increased cooling air velocity, and more physical space. Each of these factors could have significant cost impact, schedule impact (if redesign was required), and the ensuing product might be unavoidably noisier. It would be up to the responsible product engineer to choose the course of action that would best meet product needs.

Relevant and consistent design thermal limits should be the goal for every product development effort.

- There is no simple answer to the question of the accuracy of the thermal guideline limits. Limits based on safety requirements are firm and fixed, unless there is a clear case to be put forth to the Regulatory agencies. Reliability based limits are far less certain; the complexity of the product and its expected useful life could easily be used to justify changes of +/- 20 C. As manufacturing processes mature and become more stable, components that initially had acceptable life at, say 85 C junction, may now have the same life at 100 C junction. The use of *guideline* limits has been adopted largely for these reasons. Appropriate design limits are product and application

dependent and, therefore, the product engineer is ultimately responsible for setting these.

- As a product is being developed, the precept put forth in DEC STD 120 is to base the thermal design on design limits that are typically 25% lower than maximum limits. This margin provides for a degree of uncertainty and error that is inevitably present in all but the simplest of design efforts. As the design develops, and actual conditions are measured, and there is margin on the safe side of the maximum limits, conscious and reasoned judgement may be applied to an assessment of the risk entailed in exceeding design limits in a small number of instances. Such a judgement may have little or no impact on cost or schedule; whereas, if maximum temperature limits are exceeded, a design change could be necessary and could very well impact cost and schedule.

For items with reliability based design thermal limits, the present guidelines have, historically, resulted in products that meet customer expectations. Therefore, approval of a product design containing items that exceed these guideline values, should only be done with a firm technical basis.

4.6 LIMIT LOCATION

Wherever possible, thermal limits should refer to a specific location on or in an item. This location should either be directly accessible for measurement or easily corrected by the use of a nearby measurement, as discussed in DEC STD 120, Section 5.4.

This nearby measurement should be as close a practical to the limit location and it should be a conductive thermal connection, if possible, characterized by the expression kA/l . Refer to DEC STD 120-4, Thermal Measurements Guide for a more detailed explanation of measurement techniques and correction procedure.

For convenience, Table 1, summarizes some of the commonly used corrections for *nearby* location measurements.

Table 1: TYPICAL LIMIT LOCATION TEMPERATURE CORRECTION

ITEM	MEASUREMENT LOCATION	CRITICAL LOCATION	CORRECTION C	SOURCE
Logic Devices ^{1 2}	case hot spot	at junction		
Plastic	adjacent die attach		10	E
Ceramic	adjacent die attach		5	E
Ceramic	on lid		10	E

¹These values are approximate and may be significantly lower, depending on die size, die attach, heat output, and package construction. If, after applying these differences, the device in question will not meet its design thermal limit, then a more specific and more accurate estimate should be made.

²For multi-watt packages, use 2 to 3 C/watt initially, followed up by thermal analysis or specific thermal measurement.

SOURCE CODES

- A - Digital Test Data
- B - Manufacturer's Data
- C - Digital Component Specification
- D - DEC STD 119 Product Safety
- E - Estimated

Table 1 (Cont.): TYPICAL LIMIT LOCATION TEMPERATURE CORRECTION

ITEM	MEASUREMENT LOCATION	CRITICAL LOCATION	CORRECTION C	SOURCE
Power Devices ²	case hot spot	at junction		
Monolithic Regulators			2 C/W	E
Transistors			2 C/W	E
Rectifiers			2 C/W	E
Diodes			2 C/W	E
Oscillators	case hot spot	at junction	2 C/W	E
Hard Disk Drive HDA	top surface	media	1 - 2	E
Batteries	surface	at center	2	E

²For multi-watt packages, use 2 to 3 C/watt initially, followed up by thermal analysis or specific thermal measurement.

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5 TEMPERATURE LIMIT GUIDELINES**5.1 TEMPERATURE LIMITS - RELIABILITY BASED**

The majority of the temperature limits used in the design of Digital products are based on reliability considerations. An example of this may be found in *TEG Memo 85-0104* where design temperature limits for MOS and Bipolar devices are recommended.

Specific reference to the basis for the setting of these guideline values is included in Table 2 under the SOURCE column. The intention is to give the responsible engineer this basis so that its application to the specific product, under design, may be assessed.

As these limit guidelines are based on a general reliability assessment, component limits higher than those presented in Table 2 below, may be set based on specific reliability data, as provided for in DEC STD 120-0, Section 6.

For most items, the design limit value appears to provide acceptable product life. However, there is no specific study that supports this contention.

It is also important to note that for the typical Digital product there are a large number of individual components, such as logic and power devices. However, only a small percentage, 5 to 10 %, are typically approaching their design temperature limits in a given product

Table 2: TEMPERATURE LIMITS - RELIABILITY BASED

ITEM	LOCATION	DESIGN ¹²	MAXIMUM ²	SOURCE
		C	C	
Logic Devices ^{3 4}	at junction			
Bipolar		110	150	E
MOS		85	130	E
Power Devices	at junction			
Monolithic Regulators		100	125	E
Transistors/Rectifiers/Diodes				
MAX Limit of 125 C		100	125	E (Surge Limit 115 C) ⁵
MAX Limit of 150 C		105	150	E (Surge Limit 130 C) ⁵
MAX Limit of 175 C		115	175	E (Surge Limit 150 C) ⁵
MAX Limit of 200 C		125	200	E (Surge Limit 170 C) ⁵
Inductive Devices ⁷	hot spot ⁶			
Class 105 (A) insulation		90	105	E
Class 120 (E) insulation		100	120	E
Class 130 (B) insulation ⁴		105	130	E
Class 155 (F) insulation		125	155	E
Class 180 (H) insulation		145	180	E
Capacitors (85 C rated)	any point	70	85	E
Capacitors (105 C rated)	any point	90	105	E
Resistors	at element	140	170	E
Oscillators	at junction	100	130	E
CRT Glass tube	adj to heater	100	130	E
Hard Disk Drive	top surface	55	60	C/E
Magnetic Media	on media			
Normal (TK50)		38	40	C
Hi Temp (TK52)		47	49	C
Floppy Disk		49	52	C
Fan(s)	flowing air	60	70	C
Batteries	at center	60	70	C

¹These design values are starting points that may be raised or lowered to achieve design product reliability, as discussed in Section 9.1.

²It is the responsibility of the responsible engineer, as named in the Option/Module Hardware List, to set these limits as a part of the Product Thermal Design Requirements, as outlined in DEC STD 120-0, Section 2.2.1.

³Bipolar includes most types of TTL (transistor-transistor logic) and ECL (emitter coupled logic), bipolar memory logic, and bipolar linear logic. MOS (metal oxide semiconductor) includes most types of MOS logic, memory, and linear devices.

⁴See Section A.2, reference 1, for an explanation of the basis for these limits.

⁵Applies to current draw surges of less than 1 minute duration with an expected duty cycle of less than 1 percent (such as; disk start-up).

⁶See Section A.3, reference 1, Section 5.1.8.3, for an explanation of *hot-spot*.

⁷Inductive devices include coils, CRT yoke, transformers, line filters, fan cores, and any other magnetic devices.

SOURCE CODES

- A - Digital Test Data
- B - Manufacturer's Data
- C - Digital Component Specification
- D - DEC STD 119 Product Safety
- E - Estimated

5.2 TEMPERATURE LIMITS - SAFETY BASED

Temperature limits based on safety considerations are determined from maximum temperature limits in *DEC STD 119 Digital Product Safety* and other Digital standards that have safety based requirements. A listing of Digital standards known to have safety based thermal limits may be found in Section A.1 below.

For Thermal Design Verification Testing (as required by DEC STD 120-0, Section 5) and for DEC STD 119 testing, the requirement is to not exceed these maximum temperature limits.

Table 3: TEMPERATURE LIMITS - SAFETY BASED

ITEM	LOCATION	DESIGN GOAL ⁵	MAXIMUM	SOURCE
		C	C	
SS/DS PWB (TYPE 1)	any point	*	130	F ¹
SS/DS PWB (other)	any point	*	105	F ¹
Multilayer PWB	any point	*	105	F ¹
Exterior surfaces - subject to contact during intended use	any point			
Metal		*	60	D ¹
Glass		*	70	D ¹
Plastic, rubber		*	85	D ¹
Exterior surfaces - other	any point			
Metal		*	70	D ¹
Glass		*	80	D ¹
Plastic, rubber		*	95	D ¹
Magnetics ³	outer insulation surface			
Class 105 (A) insulation		*	100	D ²
Class 120 (E) insulation		*	115	D ²
Class 130 (B) insulation ⁴		*	120	D ²
Class 155 (F) insulation		*	140	D ²
Class 180 (H) insulation		*	165	D ²
Capacitors (85 C rated)	any point	*	65	D ²
Capacitors (105 C rated)	any point	*	85	D ²

¹These values apply to an actual measurement at any point on or in the Printed Wiring Board (PWB) or surface. In thermal simulation, these items are usually represented in a model or prototype as one node (or a small number of nodes) or an element with uniform heat output. The design temperature goals, for such simulated surfaces, are as listed in Table 4.

²See Section A.2, reference 2, for an explanation of the basis for these limits.

³Magnetics include coils, CRT yoke, transformers, line filters, fan cores, and any other magnetic devices. DEC STD 119 derates the limit by 10 C if an outer surface thermocouple temperature is used.

⁴Digital default minimum value.

⁵It is left to the discretion of the responsible engineer to select design temperature goals.

SOURCE CODES

- A - Digital Test Data
- B - Manufacturer's Data
- C - Digital Component Specification
- D - DEC STD 119 Product Safety
- E - Estimated
- F - DEC STD 030 Module Manufacturing

Typically, prudent thermal design practice would be to begin a design with temperature goals that are lower than the maximum limits. One such approach would be to start with 75 percent of the temperature rise allowed in DEC STD 119-01. However, this setting of safety-based design temperature goals is left to the discretion of the responsible engineer.

5.3 TEMPERATURE LIMITS - OPERABILITY BASED

A component will operate satisfactorily within a circuit, up to a specific temperature. Above the specified temperature operation is faulty, intermittent, or otherwise unsatisfactory. When this component is cooled below its specific temperature, satisfactory operation resumes. This condition is distinguished from reliability based failure in that it is *reversible*. At present, there are no known operability based limits that are more restrictive than the reliability based limits. Although operability based limits are uncommon, it is possible that such limits will be necessary from time to time.

6 DESIGN TEMPERATURE GOALS FOR SIMULATION STUDIES

Early in product design, where product concept alternatives are evaluated analytically or experimentally using thermal network modeling or prototype simulation techniques, the available thermal design information is approximate and incomplete. However, the thermal engineer must provide some assurance that the design approach and concept is thermally viable. At this point in the design process, it is important to define design temperature goals for these simulation efforts where the simulation is distinctly different (usually simplified) from the end design.

Typically, a PWB would be represented by a single node in a thermal network model or a bare copper-clad piece of FR4, cut to the expected board size and powered with a heater pad. With either method, the result will be an average temperature for the simulated PWB.

If the simulation is specific, with regard to a particular component (such as an IC device package/with heatsink) then the temperature limits from Table 2 or Table 3 should be used.

As it is important to assess the results of such simulations in a consistent manner, the temperature limits in Table 4 are offered as guidelines. Their use should be limited to evaluation of simulations that are simplified with uniform (or near uniform) temperature distribution substituted for the real situation, where temperature is nonuniform.

NOTE

These simulation temperature goals are not to be used as the basis for acceptance, as called for in DEC STD 120-0, Section 5.7

Table 4: SIMULATION TEMPERATURE GOALS

ITEM	LOCATION	DESIGN	SOURCE
		C	
PWB	average ¹		
MOS based		70	Estimated
Other		85	Estimated
Power Supply		90	Estimated
External surface	average ¹		
Metal		55	Estimated
Plastic		70	Estimated

¹These values apply to a simulated average temperature for the board or surface. Use Table 2 or Table 3 for specific components.

7 DESIGN TEMPERATURE RANGE LIMITS

At this time, there are no known requirements that are more stringent than the present Design Thermal Environment Classification, defined in DEC STD 120.

8 DESIGN RATE OF CHANGE OF TEMPERATURE LIMITS

There is no agreement on these limits.

9 SETTING ALTERNATIVE THERMAL LIMITS

Lower or more stringent Thermal Limits

Design thermal limits that meet or are more stringent than these guideline values may be set without additional documentation, as noted in DEC STD 120-0, Section 6.2.1. See also the discussion in Section 4.5.

Higher or less stringent Thermal Limits

Design thermal limits that are less stringent than these guidelines may be set, provided that the technical basis for the less stringent value is identified, as required in DEC STD 120-0, Section 6. See also the discussion in Section 4.5.

9.1 DESIGN TEMPERATURE LIMITS FROM TEMPERATURE VERSUS RELIABILITY DATA

Temperature versus reliability data may be used to establish design temperature limits for components or subassemblies. In such instances, either a summary of or a reference to the temperature versus reliability data shall be included in the Thermal Design Requirements section of the product specification, as outlined in DEC STD 120-0, Section 6.2.2.

9.2 CALCULATING DESIGN TEMPERATURE LIMITS FROM MAXIMUM TEMPERATURE LIMITS

A design temperature limit for components may be calculated from a maximum temperature limit only if the thermal guidelines herein do not apply and if temperature versus reliability data is not available. The resulting design temperature limit shall be used cautiously and an effort should be made to substantiate the value.

The calculated design temperature limit is determined using an assumed environment temperature of 32 C (Class A per DEC STD 102-1), regardless of the environmental classification of the system.

To calculate the design temperature limit, multiply the temperature difference between the maximum temperature limit and 32 C by the factor 0.75, then add this value to the assumed environment temperature (32 C). For example, given a maximum temperature limit (MTL) of 150 C, calculate the design temperature limit (DTL) as follows.

$$DTL = 32 + 0.75 * (MTL - 32) = 32 + 0.75 * 118 = 120.5C \quad (1)$$

10 USING THIS GUIDELINE

To use the guideline limits, select temperature limit data from Tables 1 or 2, for the components or items in the product under design. If the item or component is not listed in these tables, then temperature limit data may be set following the procedures in Section 9. If the same item is in each table and has different temperature limits, then use the more stringent value.

Record this data in the Thermal Design Requirements section of the Product Engineering Design or Purchase Specification, as required by DEC STD 120-0, Section 4.2. It is then available as an aid in setting the thermal design parameters, or features, in the product design and also for use during the product thermal design verification testing.

11 UPDATE PROCEDURE

Users of this guideline are encouraged to submit specific technical information or data that will:

- a. Justify any guideline value (particularly those that have been estimated).
- b. Provide the basis for changing any guideline value.
- c. Provide the basis for a new guideline value.

The preferred method would be to submit a report or memo to the standard owner. As this guideline may be updated without formal review, any proposed revisions will be submitted to the DEC STD 120 Advisory Committee. On acceptance, the changes would be made and reference to the submitter's documentation would appear in Section A.2 below.

GLOSSARY

design temperature limit: The highest temperature at which a component, subassembly, or unit can reach, during steady state conditions, in a powered product under design. This temperature refers to a temperature at a specific location on or in the item. Also see Section 4.2.

design thermal environment classification: The environment or externally imposed conditions in which a product must operate. That is, the maximum environment or local environment temperature, the maximum variation in environment or local environment temperature, and the maximum rate of change of environment or local environment temperature. See DEC STD 120-0, subhead 4.3 for a complete set of requirements for different product types.

maximum temperature limit: The highest operating temperature at which a component is safe or is warranted for continuous operation by the manufacturer. This temperature is measured at a specific location on or in the item. Also see Section 4.2.

product environment classification: Classifications defined in *DEC STD 102-1 Environmental Standard for Computers and Peripherals - Temperature, Humidity, and Altitude Requirements* that define classes of operating environments for Digital products based on temperature and humidity.

thermal network model: A lumped-parameter representation of a physical system, whose behavior is governed by diffusion-type equations.

thermal resistance (case to environment): A measured or calculated value indicating the resistance to heat flow, typically in units of temperature difference per unit of heat flow, from a referenced location on a device case or package to the local environment or the surrounding air. For both forced and natural convection, the surrounding or local air temperature is meant to be the temperature of the bulk air outside the thermal boundary layer that occurs immediately adjacent to the device in question.

thermal resistance (junction to case): A measured or calculated value indicating the resistance to heat flow, typically in units of temperature difference per unit of heat flow, from a device die or chip to a specified external location on the device enclosure or case.

APPENDIX A REFERENCED DOCUMENTS

A.1 EL-Class Digital Documents

EL-Class Number	Document Title
EL-00012-04	<i>DEC STD 012-4 Unified Numbering Code (UNC) - Software Numbering Conventions</i>
EL-00030-02	<i>DEC STD 030-2 Module Manufacturing Standard - Product Safety Requirements</i>
EL-00119-01	<i>DEC STD 119-1 Digital Product Safety - Design Criteria</i>
EL-00120-00	<i>DEC STD 120-0 Product Thermal Design Standard: Design Requirements</i>
EL-00176-02	<i>DEC STD 176-2 Printed-Wiring Board Product Safety Criteria</i>

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A.2 Other Digital Documents

Document Number	Document Title
TEG MEMO 85-0104	<i>New Junction Temperature Limits (Author: John Bartoszek)</i>
TEG MEMO 89-0019	<i>Product Safety Temperature Limits (Author: William Bell)</i>

A.3 Other Documents

Document Number	Document Title
MIL-HDBK 217E	<i>Reliability Prediction of Electronic Equipment</i>

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